THE U. S. RIA PROJECT SRF LINAC*

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Abstract

The nuclear physics community in the U. S. has reaffirmed the rare isotope accelerator facility (RIA) as the number one priority for new construction. This paper reviews the present status of the benchmark design and SRF component development for the 1.4 GeV multi-beam ion driver linac.

1 INTRODUCTION

The evolving plans for the U. S. rare-isotope accelerator facility (RIA) and its associated driver linac have been described previously [1, 2]. A principal element of RIA will be a superconducting, 1.4 GeV ion linac capable of accelerating ions of any stable isotope from hydrogen to uranium, and delivering several hundred kilowatts of beam onto production targets at energies of 400 MeV/nucleon for uranium and more than 900 MeV for protons. The highly-flexible driver linac [3] can provide a variety of beams to utilize combinations of projectile fragmentation, target fragmentation, fission, and spallation to produce a very broad assortment of short-lived unstable isotopes.

Great flexibility is obtained by configuring the driver as an array of short, independently-phased superconducting cavities. The cavity array can be tuned to provide a variable velocity profile, which provides good efficiency over the full mass range of ions, protons to uranium. The array of short cavities also ensures very large longitudinal and transverse acceptance, opening the possibility of accelerating beams of multiple-charge states [4,5,6], a novel mode of operation. Using multiple-charge-state beams substantially increases current for ion-source-performance limited beams, and also enables the use of multiple strippers without substantial loss of beam, which reduces the size and cost of the driver linac.

The driver linac, shown schematically in Fig. 1, will utilize an ECR ion source injecting a short cw normally-conducting RFQ which will produce a 170 keV/nucleon beam bunched at 57.5 MHz, which is injected into an linac array of some 416 SC cavities.

The benchmark configuration was first defined within a RIA driver working group, chaired by Christoph Leeman, which met several times during 1999, and was part of the report [7] of the ISOL task force to the U.S. Nuclear Science Advisory Committee (NSAC).

This paper will discuss changes in the linac configuration since that time. Most of these changes were discussed in a RIA driver workshop chaired by the author in June 2000, and were incorporated in the January 2001 cost rev-

Figure 1: Schematic of the RIA driver linac

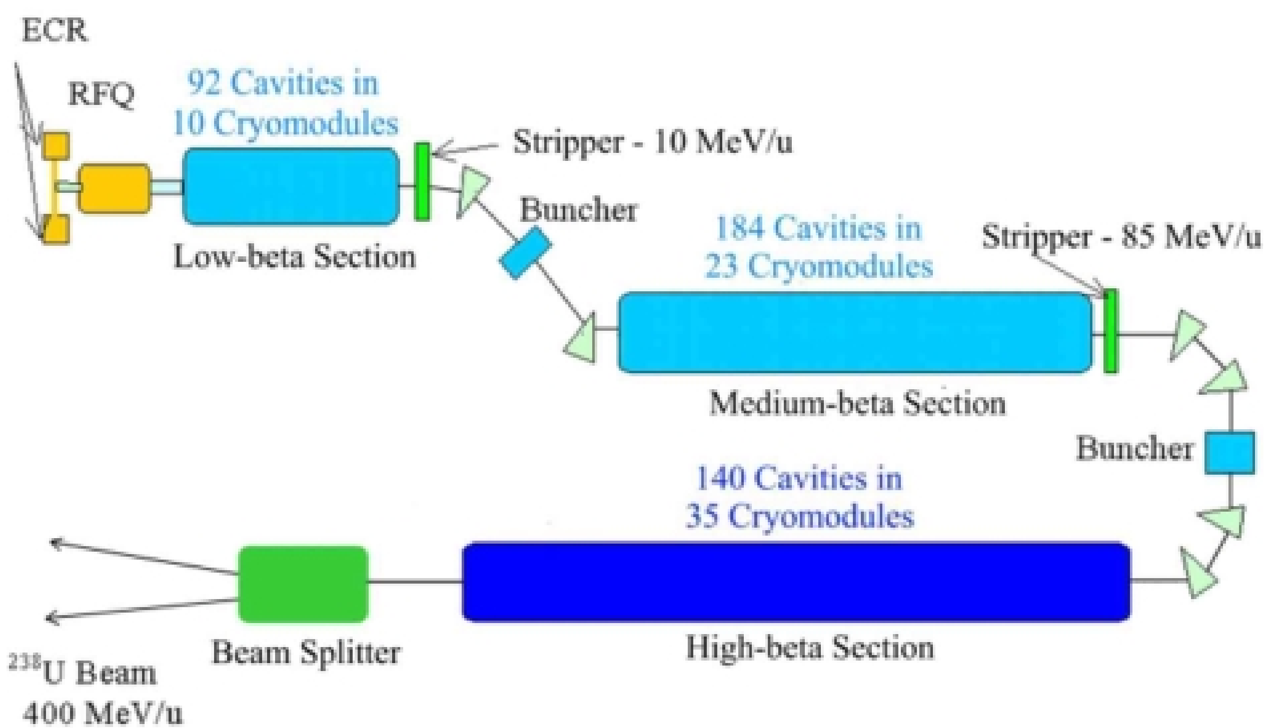

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Table 1: Properties of the SC resonator array for the RIA driver linac

#	Beta	Class	Freq	Length	Eacc	Voltage	Phase	No. Cavities / Section		
			(MHz)	(cm)	(MV/m)	(MV)	deg.	Injector	Middle	Final
1	0.024	3 DT	57.5	20	4	0.69	-30	2		
2	0.031	3 DT	57.5	25	4	0.87	-30	5		
3	0.061	1 DT	57.5	20	5	0.87	-30	40		
4	0.150	1 DT	115.0	25	5	1.08	-30	45		
5	0.252	1DT	172.5	30	5	1.30	-30		104	
6	0.393	2 DT	345.0	36	5	1.56	-30		80	
7	0.490	6 Cell	805.0	55	10.54	5.00	-30			48
8	0.610	6 Cell	805.0	68	13.01	7.68	-30			64
9	0.810	6 Cell	805.0	91	15.99	12.54	-30			28

iew of RIA, conducted in January 2001 by a group led by Michael Harrison, which also reported to NSAC.

2 ELEMENTS OF THE LINAC

Table 1 outlines the properties of nine different types of superconducting niobium cavities which span a range in velocity from $0.02 < \beta = v/c < 0.9$ and a range in frequency from 57.5 to 805 MHz. Sections of the various cavities are shown to scale in Figure 2.

Of these nine types, the first four closely resemble existing cavities which were developed for, and have been operating for years in several existing SC heavy ion linacs [8]. The last two cavity types, the 805 MHz $\beta = 0.61$ and $\beta = 0.81$ six-cell cavities, are both presently being developed at JLAB for the SNS project [9]. SNS is also funding development to sustain operation at anticipated peak surface fields of 35 MV/m.

The remaining three cavities, covering the relatively unexplored [10] velocity range $0.24 < \beta = v/c < 0.55$, are the highest SRF development priority for the presently ongoing, funding-limited R&D specifically directed toward RIA [11,12,13,14,15, 16].

2.1Major changes in the cavity configuration

Major changes since the 1999 RIA driver working group are:

1. The frequency of the high-velocity elliptical-cell cavities has been changed from 700 MHz to 805 MHz to utilize the $\beta = 0.61$ and $\beta = 0.81$ cavities being developed at JLAB for the U.S. spallation neutron source (SNS) project. Using higher-frequency shorter cavities requires a modest increase in cavity count, but this is compensated by reduced R&D costs. Also the SNS project is developing a higher velocity cavity than had been assumed for RIA, and by employing 7 cryomodules of the SNS $\beta = 0.81$ cavity, the RIA driver can increase the output energy of the lighter beams; in the case of protons, by more than 100 MeV.

2. Following the RFQ, a section of normally-conducting (NC) IH-type structures has been replaced by a single cryomodule with seven SC four-gap interdigital cavities of two different types. The parameters of these cavities are well within the frequency and velocity range of presently operating SC interdigital cavities[17], and will call for little additional R&D. The cost of the supercond-ucting option is essentially the same as for NC IH structures, but the aperture, transverse acceptance, and beam quality are substantially increased. The SC option would accommodate a two-charge-state injector RFQ [18], which could provide a factor of two increase in uranium beam current, if, as presently anticipated, ECR ion source output is the limiting factor.

2.2 Drift-tube cavities

The first six cavity types are all drift-tube loaded cavities of relatively low frequency, assumed to operate at 4 K, and the assumed accelerating gradients are limited to values that have been achieved in operation of at least the most recently constructed portions of existing SC ion linacs.

In light of recent R&D results in single-cavity tests, this performance projection could be considered conser-vative[14,19,20]. However, it should be noted that the drift-tube section *must* perform at the assumed gradient in order to produce a useful uranium beam. Any perfor-mance shortfall will cause the beam velocity to fall below the velocity acceptance window at the entrance of the high-beta section, and the beam will not be accelerated.

The 4th and 5th cavities in Table 1 are both single drift-tube cavities, and replace two-drift-tube cavities called for in the 1999 benchmark linac. The reasons for this change are twofold:

1. Maintaining a reasonable outer diameter for the originally proposed split-ring and lollipop cavities

produced peak surface RF magnetic fields in excess of 750 gauss at the assumed 5 MV/m gradient. Such high magnetic fields could become performance limiting if the peak surface electric field is increased, as recent development tests of drift-tube cavities using high-pressure water rinse cleaning techniques seem to indicate[14,19,20].

2. Detailed ray tracing through the cavities has shown that beam deflection by rf magnetic fields can be problematic in the driver linac, particularly for the lighter ions. Such steering effects are small in spoke-loaded and half-wave types of cavities, but can be objectionably large in QWR cavities. Steering can be fairly well corrected in single drift-tube QWR cavities [21], but in two-drift-tube QWR structures, such as the lollipop and split ring, no adequate method of correction is known.

Development of the intermediate-beta spoke cavity is proceeding well. In recent tests at ANL and LANL, two 340-350 MHz single-cell spoke-loaded cavities have shown excellent performance, achieving accelerating gradients substantially above the 5 MV/m projected for RIA [14,20]. A prototype of the 345 MHz two-cell spoke cavity for RIA is nearing completion at ANL, and is expected to be tested in early next year[12].

Construction of two more prototype cavities at ANL, the 172 MHz, $\beta = 0.25$ half-wave and the 115 MHz $\beta = 0.15$ QWR shown in Figure 3 is underway and expected to be completed in calendar year 2002.

2.2 805 MHz six-cell cavities

The 805 MHz elliptical-six-cell cavities for the high-velocity section of the driver linac are an extension to lower velocities of the technology developed for SC electron linacs. This high-velocity section of the driver is quite distinct from the low-velocity section. Because of the higher RF frequency, for example, these three cavity types will operate near 2 K..

Development of the $\beta = 0.61$ and 0.81 six-cell cavities, together with associated cryomodules, couplers, and tuners is funded by the U.S. SNS project, and the work being performed by the SRF group at JLAB. As is reported at this workshop [22], this effort is proceeding well..

The cavities, cryomodules, and couplers developed for SNS can be used nearly as-is for RIA. The major differences are that the RIA driver will operate CW rather than pulsed, as for SNS, and that the RIA driver will be provide a variety of ion beams, from protons to uranium. Peak beam current will be substantially smaller for RIA than for SNS. Also, the RF systems for RIA will require substantially less RF power, probably determined by the requirement of maintaining phase control in the presence of microphonics.

The additional 805 MHz, six-cell cavity required for the RIA driver, the $\beta = 0.5$ structure, is being developed jointly by JLAB and NSCL. A single-cell cavity has been constructed and tested initially at JLAB, and subsequently at NSCL with excellent results [15,16]. A prototype six-cell unit is under construction at NSCL with completion expected within the next year. In addition to determining the possible accelerating gradient, the prototype tests will allow determination of the level of microphonics and establish the parameters for RF phase control of this highly-foreshortened cavity which will may prove to be an important element in firming up the cost of the RIA driver.

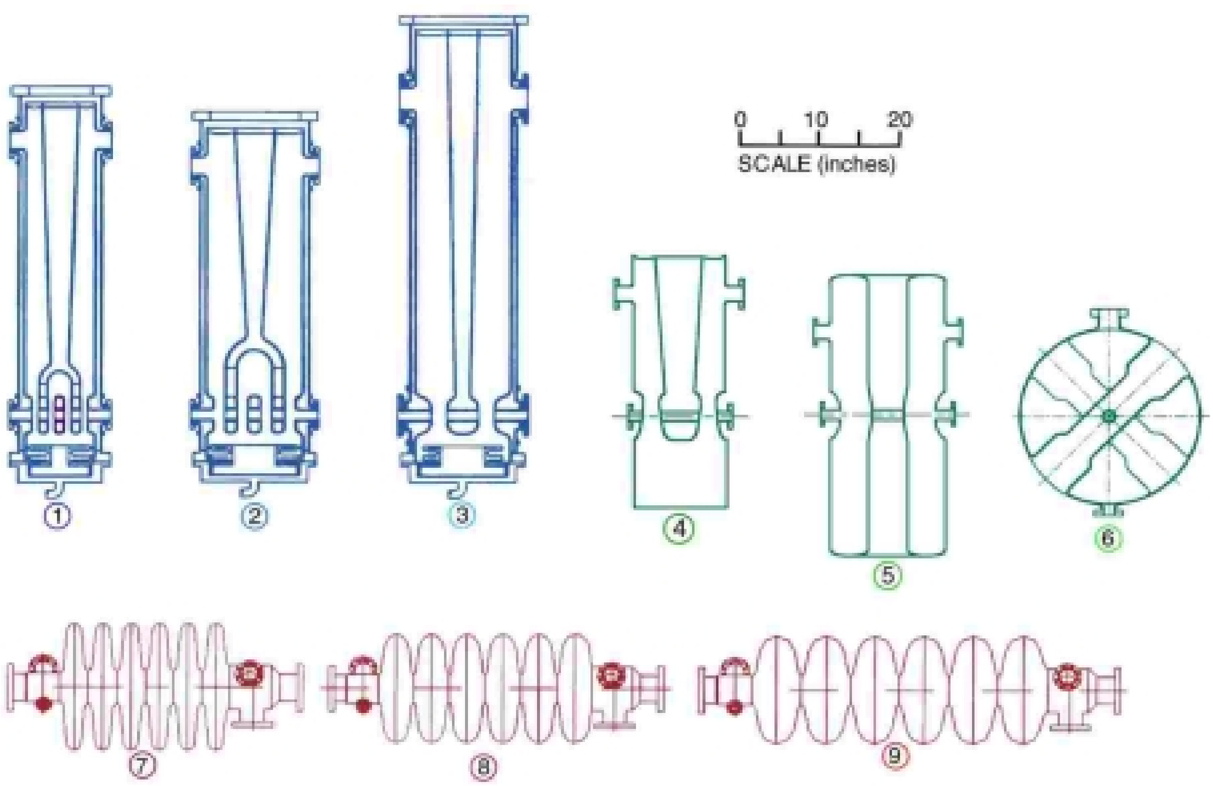
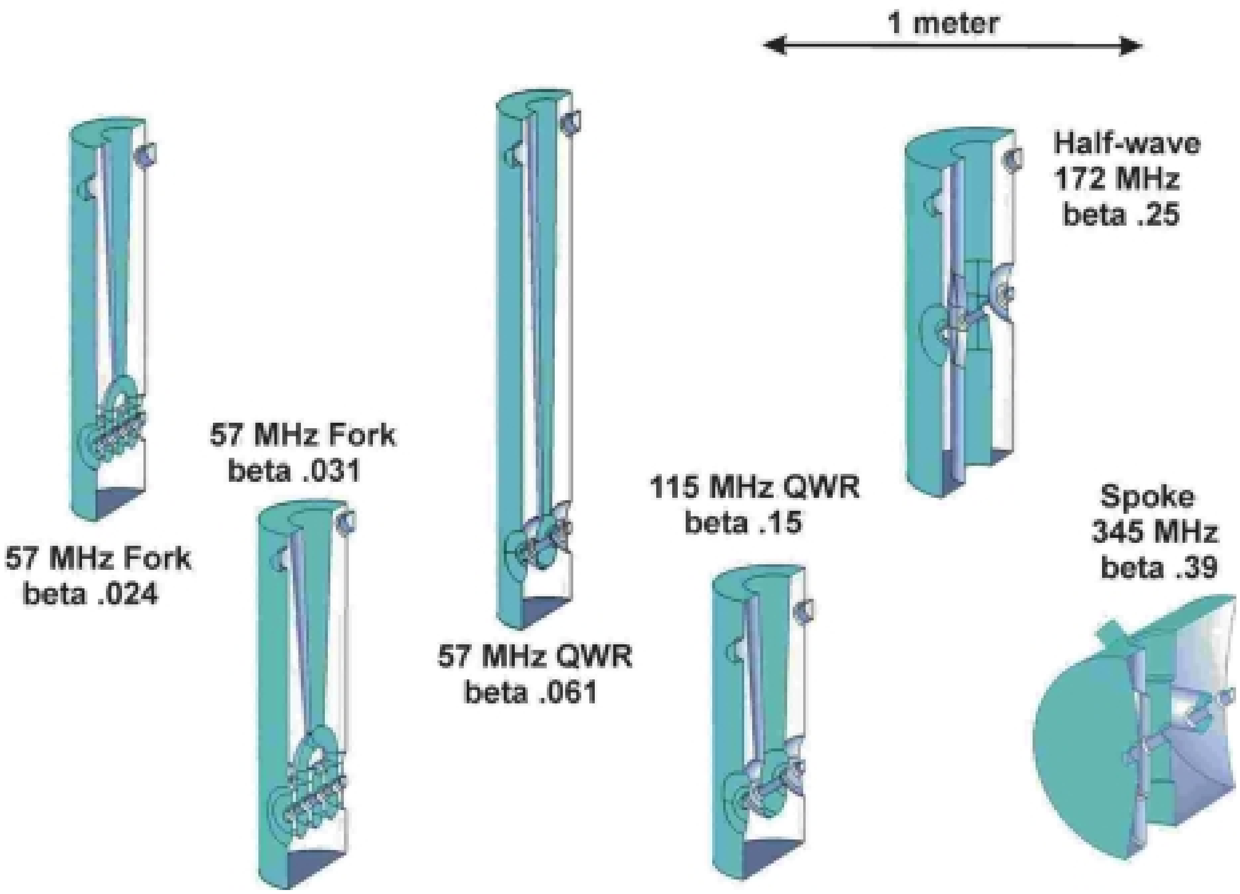


Figure 2: Sections of nine types of SC accelerating cavity which span the velocity range $0.02 < \beta = v/c < 0.9$

Figure 3: Sectioned view of six types of SC drift-tube accelerating cavity for low and intermediate velocity beams



The SNS project has set a performance goal for cavities and cryomodules of peak surface electric fields of 35 MV/m. The necessary R&D, which will focus on cleaning and handling techniques, is being carried out at JLAB as part of SNS construction [22]. Since this R&D will be complete before RIA construction begins, the SNS performance level has been incorporated into the specifications for the RIA driver shown in Table 1 above.

3 CONCLUSIONS

The excellent results obtained to date with prototype SC cavities for intermediate particle velocities indicate that there are no 'show-stoppers' in building a highly versatile SC ion linac for a driver for the proposed U. S. RIA facility at substantially the level of performance and cost estimated by various study groups over the past two years.

RIA specific SRF development currently underway includes prototyping of all the required resonator types. If time and funding permit, tests of cryomodules for the drift-tube cavities as well as for the elliptical cell cavities, including operation at gradient for extended periods of time (including development of improved cleaning and handling techniques) could provide substantial benefit. If such cryomodule tests confirm the trend to higher surface electric fields that is evidenced in recent single-cavity tests, significant reduction in the cost of the RIA driver linac could possibly be achieved.

4 ACKNOWLEDGEMENTS

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